Influence of Emulsifier Content on Properties and Durability of Cutting Fluids

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The use of cutting fluids is well recognized for several years. To cater the needs of state-of- art machining processes, several fluid formulations are available in the present day market. Of such available fluids, water-soluble fluids are dominant. Though, the need of cutting fluids is explored, the functionality of different ingredients of the fluid is not much investigated. The present work is an attempt to study the role of emulsifier on the properties and performance of cutting fluid. In the present part of the paper, estimation of basic properties and microbial contamination of the fluids with varying emulsifier contents is dealt.
Keywords*: metal cutting, cutting fluids, emulsifier, microbial contamination*

Introduction

Cutting fluids have been extensively used in metal cutting industry for several years. Initially, cutting fluids were simple oils applied with a brush to cool and lubricate the cutting tool. As the cutting operations have become more severe, the formulations of the fluids became more complex. Today, a spectrum of different formulations is available to cater the needs of the metal cutting industry which can be broadly classified as neat oils, synthetic fluids and water-soluble oils. Water-soluble oils, more popularly referred as soluble oils, find their application, in over 80% of metal cutting operations (Aronson, 1994). These fluids are mixtures of oil and water blended with emulsifiers. Soluble oils offer improved cooling capabilities and lubrication due to the blending of oil and water. They also tend to leave a protective oil film on the metal surface and prevent corrosion (Stanford & Liser, 2002) (Childers, 1994). Hardness of water affects the oil emulsion stability and thereby the functionality of the fluid (Rossmoore, 1976). Though cutting fluids offer numerous advantages, the mineral oils and fatty acids present in these fluids cause high levels of bacteria (Rossmoore, 1974). Extensive work is reported on the microbial contamination of the fluids, a majority of which can be attributed to H.W.Rossmoore.

There are three major types of micro-organisms involved in fluid deterioration: Aerobic Bacteria, Anaerobic bacteria and Fungi. Fungi are generally responsible for the black coloration of the fluid. However, aerobic bacteria split the emulsion and are shown to have a drastic influence on the functionality of the cutting fluids compared to the other two species (Rossmoore, 1974). Basic properties like emulsibility and prevention of corrosion are found to deteriorate with growth in contamination. Several conventional techniques like plate count and unconventional techniques like dip-slides (ASTM, 2003) are adopted to estimate the growth of bacteria over time. Though the use of biocides like formaldehyde can be looked upon as an easy answer to the problem, the effect of biocides on the workers, their toxicity and effectiveness needs to be considered before making any selection. Biocides are reported to have adverse effects on the workers with constant exposure. Further, the waste disposal regulations of various governments limit the usage of biocides. Hence it is always desirable to control the bacterial growth without the use of biocides.

Much of the work dedicated to the microbiological contamination of cutting fluids aims to estimate the growth of the bacteria in stored fluids. Though initiative has been taken to simulate the actual working conditions of the fluid (ASTM, 2003) conditions like exposure to ferrous metals, evaporation, effect of temperature on the microbiological growth is not dealt with. However, it is well known that temperature plays a key role in the formation of bacterial colonies and their sustenance. In the present work, conditions of the fluid are simulated along with the effect of temperature to get a realistic picture of the microbial growth in the fluids. Different formulations of the cutting fluids varying the content of the emulsifier have been tested and the different properties are evaluated. Tests for estimation of microbiological growth in the fluids are carried out. Paraffin oil has been used as the base oil and Sodium Petroleum Sulphonate has been used as an emulsifier. About 5% of base oil and emulsifier mixture is mixed with 95% of water to form the cutting fluid.

Sodium Petroleum Sulphonate

Sodium Petroleum Sulphonates are unique materials possessing the ability to function as both surfactants and rust inhibitors. The polar nature of the Sulphonate end of the molecule functions as a typical anionic surfactant. The tail of the Sulphonate is made up of a hydrocarbon chain, which has no charge. Sulphonates act on the surface of oil droplets by binding at the tail. The head of the Sulphonate has a polar charge, allowing the head to bond to water droplets (Fig.1). Thus, the Sulphonates can hold oil and water apart so that they can co-exist and form an emulsion.

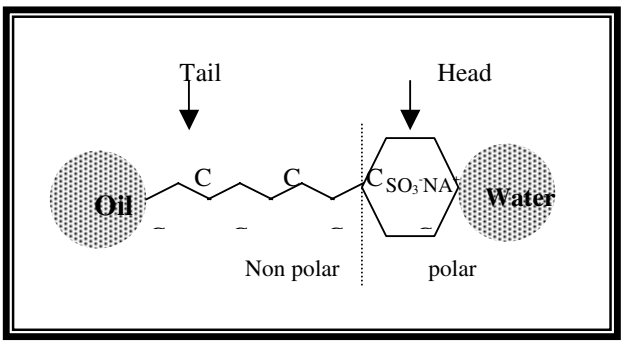

Figure 1. Schematic representation of the emulsifier molecule.

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Experiments for Evaluating Cutting Fluid Properties

In the present work, Sodium Petroleum Sulphonate in proportions of 5,10,15,20,25 percent (v/v) is mixed with the oil and is tested for evaluation of properties like Kinematic Viscosity, Thermal Conductivity, pH values and water separability for mixtures and diluted fluids (95% water).

Kinematic Viscosity

Kinematic Viscosity is one of the deciding parameters to judge the effectiveness of a fluid as a lubricant. In the present work, kinematic viscosities of the concentrates and diluted fluids are estimated using Redwood Viscometer-II and Redwood Viscometer-I respectively (ASTM, 2003).

Results presented in Table.1. show the increase in the viscosity of the mixtures with rise in the proportion of Sodium Petroleum Sulphonate (SPS). This indicates increased lubricating properties of the fluid with increase in the content of SPS. Table.2. shows the change in kinematic viscosity of diluted fluids. As the temperature increases, the rate of decrease of kinematic viscosity is less for diluted fluids compared to the concentrates.

Table.1. Kinematic viscosity of concentrated mixtures, in stokes

	Percentage Emulsifier					
Temperature, ^{0}C	0%	5%	10%	15%	20%	25%
35	0.141	0.152	0.23	0.28	0.3	0.34
40	0.096	0.117	0.15	0.23	0.25	0.25
45	0.072	0.072	0.115	0.187	0.224	0.23
50	0.0423	0.06	0.089	0.154	0.194	0.204
55	0.029	0.033	0.067	0.115	0.141	0.154
60	0.014	0.01	0.039	0.075	0.088	0.113
65	0.005	0.01	0.025	0.045	0.05	0.069

Table.2. Kinematic viscosity of cutting fluids in stokes, (95% Water).

	Percentage Emulsifier				
Temperature, ^{0}C	5%	10%	15%	20%	25%
34	0.0159	0.02	0.025	0.034	0.046
40	0.011	0.0159	0.02	0.023	0.034
48	0.006	0.011	0.016	0.025	0.03
54	0.006	0.011	0.016	0.025	0.03
65	0.006	0.011	0.016	0.025	0.03

Flash & Fire Point

Determination of Flash and fire points is necessary to estimate the applicability of the fluid at high temperatures. The concentrates are tested in a Cleveland Open Cup tester to estimate the flash and fire point. The results depicted in Table.3. indicate that the rise in content of SPS decreases the flash and fire point of the fluid. The observations may lead to an inference that lesser quantities of SPS are preferable while machining high temperature conditions. Since the concentrates are further mixed in water, the flash and fire point temperatures may not influence the usage, however, in some applications concentrates may be used.

Table.3. Variation of flash and fire points with percentage of SPS.

Emulsifier Content (%)	0	5	10	15	20	25
Flash Point, ^{0}C	216	214	212	208	203	200
Fire Point, ^{0}C	224	222	220	215	210	208

pH Value

pH value is an indication of the condition of the fluid. A decrease in the pH value indicates a fall in the performance of the cutting fluid. pH values too high or low can prove hazardous to human operator and pose a problem in waste disposal. A digital pH meter is used to estimate the pH value. Table.4. indicates rise in pH value with the increase in content of SPS. The rise in pH value is characterized by rise in alkalinity of the fluid. Hence, the results indicate that increase in SPS content increases the alkalinity of the fluid. Generally, the microbial contamination takes place in acidic medium rather than in alkaline medium. The rise in pH values indicates better resistance of the fluid to microbial contamination.

Table.4.Variation of pH value with percentage of SPS.

Emulsifier Content (%)	5	10	15	20	25
pH Value	8.75	8.8	8.89	9.1	9.3

Thermal Conductivity

The prime activity of the cutting fluid is to act as a coolant. Water miscible oils have the advantage of thermal properties of water. In order to compare the efficiency of the coolants, the thermal conductivity of the fluids is estimated. Standard guarded Hot-Plate method is employed for the estimation of thermal conductivity of the fluids. The thermal conductivity of the fluids is estimated at different temperatures. Table.5. depicts the estimated values of thermal conductivity of the liquids. The results indicate rise in thermal conductivity with increase in the SPS content. However, the values of thermal conductivity are found to be less compared to water. Unlike most liquids, which show a fall in thermal conductivity with rise in temperature, the fluids show a consistent increase in the thermal conductivity with temperature. This property is inherited from water. Since thermal conductivity is found to rise with increase in content of SPS, fluids with higher SPS content can apparently be used for machining that produces higher temperatures.

Table.5. Thermal conductivity of the fluids with varying content of SPS, kW/m-0C.

Temp ^{0}C	Emulsifier Content (%)					
30	Water	5 %	10%	15%	20%	25%
35	0.615	0.224	0.2464	0.296	0.325	0.39
40	0.623	0.226	0.2486	0.298	0.33	0.394
50	0.631	0.228	0.2508	0.301	0.33	0.397
55	0.644	0.232	0.2552	0.306	0.34	0.404
60	0.651	0.234	0.2574	0.309	0.34	0.407
65	0.658	0.236	0.2596	0.31	0.342	0.411
70	0.665	0.238	0.2618	0.314	0.345	0.414
80	0.672	0.24	0.264	0.31	0.348	0.418
90	0.686	0.244	0.2684	0.32	0.354	0.425
	0.7	0.248	0.2728	0.327	0.360	0.432

Water Separability

The prime function of an emulsifier is to make water and oil miscible. Hence, tests are carried as per ASTM to estimate the water separability of the fluid concentrates. 40ml of water and 40ml of the concentrate are mixed and stirred for 5mins using a stirrer. The test is carried out for 30 mins. As the fluids are viscous, temperature of 82^0C is maintained in the test. Fig.2. shows the oil separation in the samples. Results are presented in Table.6. It can be observed that in the 1st sample (5% concentration), water separability is high as the amount of SPS may not be sufficient. In the samples containing 10% and 15% SPS, water separation is less. In the samples containing higher amounts of SPS, some quantity of SPS is mixed with the oil to form a dark mixture and as a result, since a major portion of SPS is lost to the oil, water is separated. It can be observed from the results, that water separability is least for the sample containing 10% SPS.

Figure 2.Water separability in the samples (after 30 mins).

Table.6. Test results of water separability

Content of SPS (%)	Test Time (mins)					
	5	**10**	**15**	**20**	**25**	**30**
5	5 ml of water settled at bottom	20 ml of water settled at bottom	22 ml of water settled at bottom	22 ml of water settled at bottom	23 ml of water settled at bottom	25 ml of water settled at bottom
10	No change	No change	No change	No change	2 ml of water settled at bottom	3 ml of water settled at bottom
15	No change	No change	Traces of water found at bottom	3 ml of water settled at bottom	3 ml of water settled at bottom	3ml of water settled at bottom
20	1 ml of oil separated from the mixture and 2 ml of water settled at the bottom	2 ml of oil separated from the mixture and 3 ml of water settled at the bottom	2 ml of oil separated from the mixture and 4 ml of water settled at the bottom	2 ml of oil separated from the mixture and 4 ml of water settled at the bottom	3 ml of oil separated from the mixture and 6 ml of water settled at the bottom	3ml of oil separated from the mixture and 6 ml of water settled at the bottom
25	8 ml of emulsion separated from the mixture. A dark mixture (12 ml) is formed at the bottom of oil layer and below it a white cloudy layer is formed. 5 ml of water settled at the bottom	Oil layer increased to 10 ml and dark mixture to 15 ml. White cloudy layer of thickness 45 ml. 10 ml of water settled.	Oil layer of 10 ml and dark mixture of 15 ml. White cloudy layer of thickness 40 ml. 15 ml of water.	Oil layer of 10 ml and dark mixture to of 15 ml. White cloudy layer of thickness 37 ml. 18 ml of water settled.	Oil layer of 10 ml and dark mixture to of 15 ml. White cloudy layer of thickness 32 ml. 23 ml of water.	Oil layer increased to 12 ml and dark mixture to 16 ml. White cloudy layer of 27 ml and water layer of 25 ml.

Determination of Microbial Contamination

Five different mixtures of cutting fluids are formulated varying the emulsifier content as stated earlier. Samples are tested for both storage and working conditions. For storage, the samples are taken in air-tight plastic containers and are stored in a cool and dark place.

To simulate the working conditions, a special arrangement is made. A flat electric heating element made of Nichrome wire (750 watts, 230 volts) is taken. The element is electrically insulated on both sides with mica sheet. To prevent heat losses, asbestos sheet is used as insulator on one side. The other side of the element is attached to copper plate, bent in the shape of the element (Figs. 3 and 4).

Figure 3. Individual components of heating element.

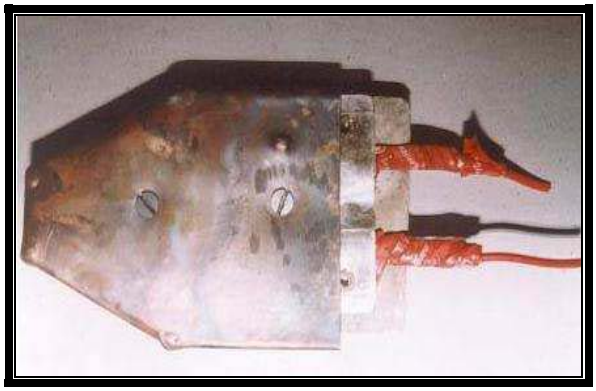


Figure 4. Assembled heating element.

The entire arrangement is fixed using screws and nuts. The element is capable of providing temperatures above 700^0C. Five such arrangements are made, one for each of the fluids. The elements are arranged on an iron mesh. Fluid in the containers is pumped onto the elements (Fig.5). Thus, the fluid falls on the heated elements and gets recirculated. Daily, the fluids are run for about 6 hrs, seven days a week, to simulate the conditions in a production unit.

Initial sample (0.1 ml) is collected immediately after the preparation of the fluids. Subsequent samples are collected from both stored and working fluids every week and are tested in duplicate by plate count for the growth of aerobic bacteria. Ready-made culture plates (Make: Himedia™, Code: FL 001) are used. The plates contain Soyabean-caesin agar as medium and NaCl as indicator. The plates are incubated for 24 hrs to estimate the growth of bacteria. Red colored colonies are observed (Fig.6 and 7) for both stored and working samples.

However the size of colonies obtained for stored samples is larger compared to working samples. Fig.8 represents the results (number of colonies) obtained from plate count of the stored samples, with different emulsifier contents. In working samples, even with dilutions, the number of colonies is innumerable; but clearly the colonies are much less in third sample compared to the other samples.

Figure 5.Pumping of fluids on the heated elements.

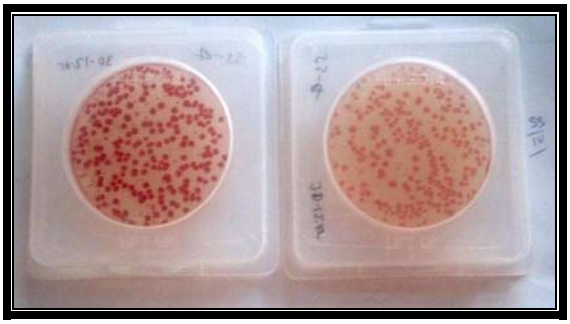
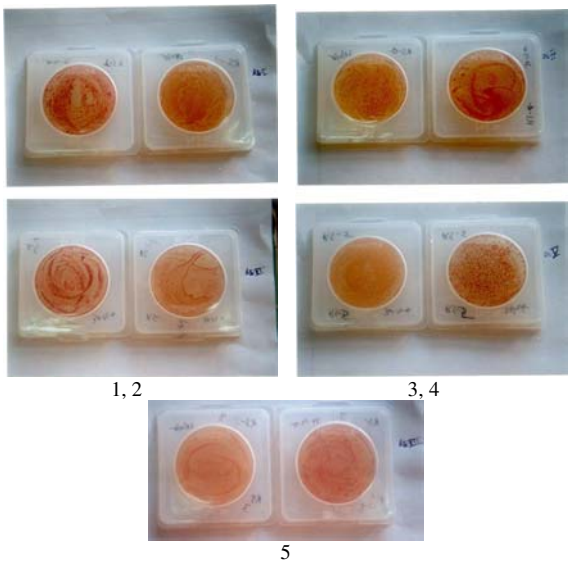


Figure 6.Colony growth in stored samples.

In order to estimate the effect of the microorganism present in the fluid, identification of the organisms is mandatory. Isolation is done and the organism is tested in various culture media and the results are presented in Table 7.

The results lead to an apparent inference that the organism present in both working and stored samples is Pseudomonas. It is noteworthy that in literature, the bacteria in stored samples are identified as Pseudomonas, but the working samples are not tested. The results obtained validate the present work as the results for stored samples are in line with the earlier studies. The genus Pseudomonas consists of aerobic, gram-negative bacilli. Being opportunistic bacteria, Pseudomonas though not invasive, has the tendency to aggravate in case of an injury or burns. There are about seventy species in Pseudomonas, a majority of which has the ability to break down the oils (which can crucially affect the cutting fluid). The organisms utilize the carbon present in the oils as their source of nutrition and deteriorate the oil in to inorganic compound. Pseudomonas has the ability to survive in hostile conditions and is not suppressed even by biocides (it is common to find Pseudomonas even in hospital disinfectants). Further, the use of biocides in the cutting fluids is subjected to several constraints imposed by the environmental regulations of various organizations. Thus the best way to control the growth of the bacterium would be to optimize the content of emulsifier.

The plate count results of stored samples are presented in Fig.7.



1, 2 3, 4

5

Figure 7. Colony growth in working samples.

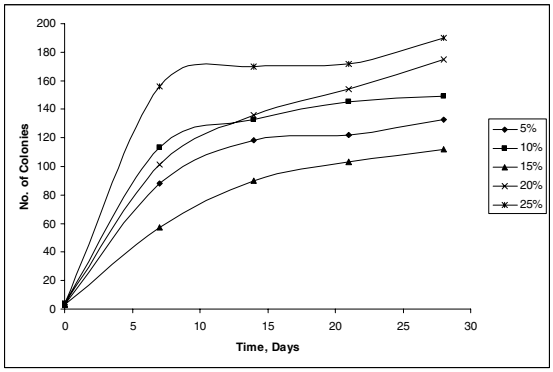


Figure8. Microbial growth in stored samples.

The results indicate least growth of micro-organisms in 3rd sample (15% emulsifier) in both stored and working samples.

Table.7. Identification of bacterial species.

Experimental Procedure	Observations	Inference
Gram Stain	Pink colored rods	G^{-ve}, rods
Agar slant cultural characteristics	Abundant thin white growth	
Fermentation	Lactose – No acid or gas Dextrose – No acid or gas Sucrose – No acid or gas	No fermentation
IMVIC	Indole – No cherry red ring	No tryptophanate enzyme
	Methyred- No red color	No acid formation
	VP- Light red color	Neutral product formation
	Citrate- Blue color formation	Citrate utilized
H_2S test	SIM medium – no black coloration	No H_2S production
Catalase	Bubble formation on addition of H_2O_2	Catalase positive
Oxidase test	Pink color changing to maroon	Oxidase positive
Geletin liquefaction	Geletin liquified	Gelatinase production
Growth in Macconkey medium	No growth	Growth observed only in Pseudomonas specific Cetrimide agar
Mannitol salt agar	No growth	
Cetrimide medium	Growth occurred	

Conclusions

- Properties like thermal conductivity, flash and fire points, kinematic viscosity, etc, increase with emulsifier content.
- Microbial contamination can successfully be controlled by varying the emulsifier content in the cutting fluids.
- Least Microbiological growth is observed for samples with 15% emulsifier for both stored used samples.

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